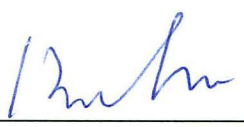


SPECIES-SPECIFIC TIME SERIES ANALYSIS OF THE IMPACT OF ALASKA POLICY
DECISIONS ON SALMON HARVEST YIELDS

By

Christopher Benshoof


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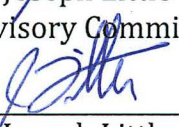
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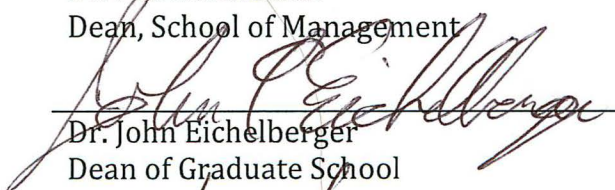


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SPECIES-SPECIFIC TIME SERIES ANALYSIS OF THE IMPACT OF ALASKA POLICY
DECISIONS ON SALMON HARVEST YIELDS

A
THESIS

Presented to the Faculty
of the University of Alaska Fairbanks

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By

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Abstract

Throughout Alaska's history, the volume of the yearly salmon harvest has been an issue of much debate. As early as the 1940s and 1950s, decreasing salmon harvests caused territorial leaders to push for Alaska statehood such that the resources could be governed by the people that lived there. Since then, various policy shifts in both 1959 and 1974 have been credited with supporting higher and higher salmon yields.

This thesis incorporates historical data from 1914-2013 for salmon harvests of Chinook, sockeye, coho, pink, and chum salmon along with environmental factors associated with the Pacific decadal oscillation (PDO) index to investigate the role that policy decisions in Alaska's history have played in the salmon industry. This cointegration relationship is studied using an autoregressive distributed lag (ARDL) bounds testing approach to create statistical models of the time series data for each of the five salmon species. Results for both short-run and long-run impacts are analyzed for each species as well as the salmon market as a whole.

The conclusions show that while there is a long-run cointegration relationship between oceanic conditions and Alaska salmon harvest, the policy changes in 1959 had no statistically significant impact on long-run salmon yield. In addition, the changes in 1974 including the Limited Entry Act and bolstered support for salmon hatcheries did have a strongly significant affect on the volume of salmon harvests. The ARDL models presented here offer a new look at historical Alaska policy while taking into account the interconnectedness of the market with the environment.

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Chapter 1 Introduction

Policy changes throughout Alaska history have been directed toward making the most of the state's resources. Where some of those policy decisions affect the mining or tourism industries, the fisheries industry has played a large role in the development of Alaska as state. During the first half of the twentieth century, the Alaska territory fisheries were managed by the federal government. At this time, most of the responsibility for industry oversight were granted to the United States Department of Commerce, and officials from Washington D.C. were supposed to maintain a presence in the territory during the fishing season to oversee salmon harvests. However, declining salmon yields in the 1940s and 1950s led territorial leaders to speak out in favor of Alaska statehood such that the citizens of Alaska could manage their own resources. Following statehood in 1959, salmon harvests continued to be low each year. In 1973 the Limited Entry Act marked a larger move toward supporting salmon fisheries. This change coincided with a stronger push to support salmon hatcheries as well, and in the decades that proceeded salmon harvests increased dramatically.

At the same time that salmon harvest fluctuations were causing trouble for Alaska leaders, long-term decadal trends in ocean condition played a role in salmon population. Researchers in Washington and Oregon have researched the impacts of Pacific decadal oscillation (PDO) on salmon populations throughout the Pacific northwest. Their work has shown a connection between oceanic temperature and the success of salmon populations. This thesis proposes to address how policy shifts in 1959 and 1973 may have impacted salmon harvests in both short term and long term as compared to the

impact that natural oceanic cycles may have had. To do this, an autoregressive distributed lag approach is taken in order to account for the cointegration of salmon harvests and PDO.

1.1 Historical Background

For the past one hundred years, Alaska's unique resource endowment has been at the center of much debate. Whether it was oil, gold, fur-seals, or fish, the question of how to create a sustainable environment for the harvesting of those resources has been the job of many territorial and state agencies throughout Alaska's history. Fluctuations in the Alaska salmon industry, however, played one of the key roles in arguing for Alaska statehood, and it continues today to be a topic of ongoing discussion (Cooley, 1963; Krueger, Zimmerman, & Spaeder, 2009). In the late 19th century, fishing in the Alaska territory was overseen by the federal government, and while the fishing industry was often at-odds with territorial leaders, the efforts of the federal overseers seemed to fall short of helping maintain a healthy salmon stock from year to year (Thompson, 1952).

As early as 1915, yearly salmon harvests took in approximately 50 million fish. This includes salmon taken and canned as part of the commercial salmon industry, as well as salmon taken for sport and subsistence. Figure 1 shows that over the ninety-eight years that followed, salmon harvests have dipped as low as 20 million in 1967, and reached as high as 220 million as recently as 2005. A visual analysis of Figure 1 shows that there appear to be two distinct periods in Alaska history with regard to salmon harvests. The years prior to 1973 show a relatively lower average salmon harvest, and the years since

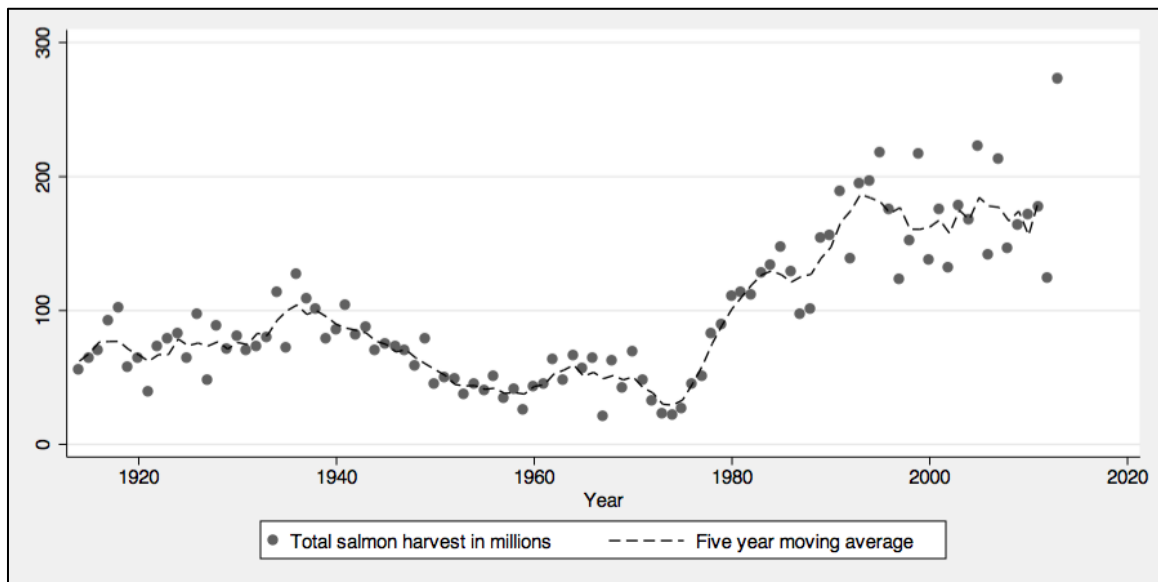


Figure 1: Alaska salmon harvests, 1914-2013

1973 have shown significant growth in the number of salmon taken each year. It was during the first half of the twentieth century that salmon harvest volumes became a serious issue.

One of the greatest concerns from territorial leaders was the wide spread use of the fish trap. A properly constructed fish trap could be used to block off as large a part of the mouth of a river as the fishermen wanted. At one extreme, it would be possible to block off the entire mouth of the river, harvesting nearly one hundred percent of returning salmon. Federal officials from Washington D.C. rarely made the trip to Alaska to check up on fishing or canning operations; while the producers did their best to harvest a sustainable number of salmon each year, Alaska leaders were not satisfied (Cooley, 1963). Eventually, the White Act of 1924 attempted to solve the problem by giving stricter permitting rights to the head of the Department of Commerce, but that did not end

the use of the fish trap. In fact, the debate over the use of the fish trap continued to build along with the movement for statehood. In 1949, the fishermen of Ketchikan and Cordova wrote a book that was summarized as “The Fish Trap – why it must go and the reasons why control of Alaska fisheries should be in the hands of Alaskans” (Liberate, 1949).

Salmon harvests were growing substantially at the beginning of the twentieth century. In fact, the salmon industry – largely run by companies based in Seattle and the Pacific Northwest – was taking in so many fish that in 1909 the Pacific Fisherman journal wrote “it [was] not a question of how to sell more salmon, but how to pack more” (Cooley, 1963). Things continued to improve and the 1940s saw a comparatively high average for the time of nearly 95 million salmon per year. This was a tremendous help to the United States efforts in World War II, as many soldiers were fed on canned salmon (Thompson, 1952). Unfortunately, following World War II, the Alaska salmon industry started taking in fewer and fewer salmon each year.

The period of decline from 1949 – 1953 hurt both the producers in the salmon packing industry and the Alaska territory as a whole. Many leaders in the territory placed the blame for the declining salmon harvests on the increasing use of fish traps and the failure of the federal government to properly manage the industry and enforce regulations (Thompson, 1952). During its active oversight, Bureau of Fisheries Commissioners would travel to the Gulf of Alaska coastline, organizing Bureau stream guards and small fleets of enforcement boats to ensure that commercial fishermen followed the guidelines placed upon their industry. Secretary of Commerce William C. Redfield characterized the

federal oversight when he “admitted in his 1914 annual report that supervision exercised by the bureau over the Alaska salmon fisheries had been more alleged than real” (Cooley, 1963). As a result, territorial leaders bolstered the charge for statehood with the argument that if Alaska were a state it could do a better job of managing its own resources. With regard to the push for Alaska statehood, economist George Rogers described the knowledge and efforts of territorial leaders when he said, “Fisheries was the key to statehood all along and Ernest Gruening recognized that” (*Starbound*, 2009).

Following Alaska statehood in 1959, the Alaska Department of Fish and Game was created and granted authority over Alaska fisheries. One of its first actions was to ban the use of the fish trap for harvesting salmon (Cooley, 1963). However, despite initial efforts at promoting greater salmon harvests and populations, the harvest volumes remained relatively low throughout the 1960s. To further combat weak salmon yields, the early 1970s saw two major policy shifts in Alaska fisheries management: the *Limited Entry Act* of 1973 and the coinciding increased support of both public and private salmon hatcheries. The years immediately following 1973 were marked by a quick and huge increase in the number of salmon harvested. When the *Limited Entry Act* passed, Alaska had just finished a fishing season that yielded about 22 million salmon. Only six years later the 1979 fishing season brought in more than 88 million, and would surpass 150 million salmon by 1989 before continuing to even greater quantities in recent decades.

The Limited Entry Act followed an Alaska constitutional amendment that allowed limiting entry into fisheries for the purpose of resource sustainability. Among other things, the act created the Commercial Fisheries Entry Commission (CFEC) and helped

redefine the way salmon fisheries were to be managed (Homan, 2006). One of the many efforts of the Department of Fish and Game as well as the CFEC was to curb unregulated salmon harvesting. Their main goal was to find a sustainable level of harvest that would create a viable industry in both the short term and long term.

While the management decisions of the Alaska Department of Fish and Game may have played a key role in the increasing salmon harvests, the increased development of hatcheries statewide were also heavily involved. Hatcheries have existed on a very small scale in Alaska since the late nineteenth century, but only a handful existed and operated mostly for scientific research purposes (Roppel, 1982). By the time Alaska was a state, feasibility studies were describing the challenges of operating private hatcheries. The difficulties investigated by Orth (1977) included the challenges of defining and legislating the property rights of salmon as a public good, and the burden of operating costs currently resting with the State.

The result of trying to balance these challenges was the Fisheries Rehabilitation, Enhancement, and Development program. This effort was first organized by the Alaska Department of Fish and Game in 1971, and resulted in an increase in the number of active hatcheries in Alaska from only 7 hatcheries statewide in 1974 to 44 hatcheries only ten years later (McGee, 2003). Since 1974 the composition of salmon hatcheries statewide has seen a mix of federal, state, and private non-profit hatcheries. Their role coinciding with the impact of the Limited Entry Act can be seen again in Figure 1 as yearly salmon harvests climb from 1974 to today.

As the discussion evolves about whether or not changes in the fishing industry, management, and methods had a significant impact on annual salmon harvest, it will be important to keep environmental issues in mind as well. Currently, Alaska produces more than \$600 million dollars worth of salmon each year (Knapp, 2013), so having a clear picture of how the environment and policy decisions impact salmon harvest worth investigating.

1.2 Pacific Decadal Oscillation

Separate from the efforts at salmon sustainability in Alaska, researchers in Washington and Oregon have spent a great deal of time studying a phenomenon termed Pacific decadal oscillation. Simply put, Pacific decadal oscillation (PDO) is a recurring pattern of interdecadal climate variability (Mantua, Hare, Zhang, Wallace, & Francis, 1997). Numerically, the PDO represents the variability in sea surface temperature (SST) in the Pacific Ocean. At the University of Washington, Francis, Hare, Hollowed, and Wooster (1998) have been compiling oceanic measurements and investigating how changes in these values impact living organisms. In their work, they describe the likelihood of a strong relationship existing between the cycles that oceanic environments go through, and the phases in other measurable population characteristics tied to the ocean. One of the strongest connections made is between oceanic conditions and the populations of Pacific salmon.

Figure 2 shows the PDO index values for the years from 1900 through 2013. The claim by PDO researchers is that the average sea surface temperature (SST) and sea level

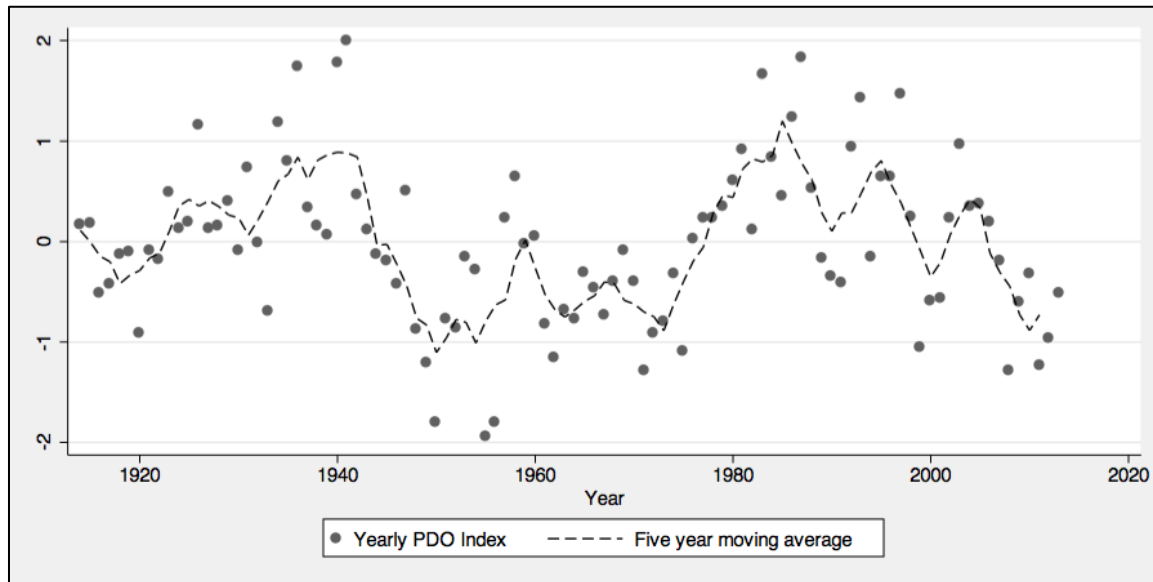


Figure 2: Pacific Decadal Oscillation (PDO) index, 1914-2013

pressure (SLP) – both combined in the PDO index calculation – go through decade-long cycles. This can be seen visually in Figure 2 where we see relatively higher values from 1925-1945, relatively lower values from 1945-1980, and relatively higher values again from 1980 through 2005. Certainly there is a great deal of variability in the PDO as it cycles through time, but large-scale oceanic regime shifts have been greatly studied in recent years.

Among other impacts, major regime shifts in the PDO – identified as occurring in the 1940s and again in the 1970s (Mantua et al., 1997) – are closely connected with salmon population. Because salmon spend a majority of their adult lives in the ocean, it is natural to discuss oceanic variability and conditions when assessing changes in these populations. Various research continues to site that factors such as sea surface temperature (Miller & Schneider, 2000) and zooplankton biomass (Francis et al., 1998)

have significant impacts upon the success rate of growing salmon in the ocean. Because of this, much of the research reviewed uses the PDO index in their models.

There is strong evidence to support the idea that a higher PDO index corresponds to a higher salmon population in the Pacific Northwest. The results of the research by Mantua et al. (1997) indicated a statistically significant decline in Alaska salmon populations in the 1940s in correspondence to a large decrease in the PDO index, and a similar increase in salmon populations in the 1970s along with an increase in the PDO index to more favorable values. Miller and Schneider summarize results showing that changes in sea surface temperature can have major impacts on how viable an ocean environment is to young salmon, showing that incorporating this value in some form would be appropriate for an econometric analysis (2000). Even factors such as the growth of oceanic zooplankton – a major source of food for young salmon – fluctuate in accordance with mean sea surface temperature and the indicating PDO index (Francis et al., 1998).

Various analyses have been conducted to better understand the connections between different populations of Pacific salmon and their common oceanic environment. This research continues to tease out the specific relationships that exist among the many subpopulations of Pacific salmon as well. Studies have gone in to investigate how salmon harvests and populations impact future generations, as well as how those generations are affected by ocean climate (Beamish & Bouillon, 1993; Noakes, Beamish, Klyashtorin, & McFarlane, 1998). With as much research on the connection between ocean conditions and salmon populations as there is, it is surprising that there are no studies connecting that to policy decisions or how changes in PDO may affect revenue.

1.3 Research Direction

The connection between PDO and salmon populations is a strong one. If the PDO index for the past 100 years is normalized, and the overall salmon harvest is also normalized, then the plot in Figure 3 is achieved. What this picture suggests is that lower PDO values (colder ocean temperatures) in the late 1940s, 1950s, and 1960s coincide with relatively low salmon harvests. In addition to the graph presented in Figure 3, the correlation between the depicted normalized moving averages for PDO and salmon harvests is 0.4361. This is a high enough correlation to warrant further research and discussion. This possible connection begs the question, “was the concern over federal mismanagement of salmon species misdirected? Was the decline in salmon harvest due to environmental factors more than policy mistakes?”

The direction of this research thesis is to look at how significant changes in Alaska policy may have impacted salmon harvests in the long run. One boundary to be investigated is 1959, when Alaska became a state, and the management of its fisheries transferred from federal agencies in Washington D.C. to right at home in Juneau, AK. At the same time, the creation of the Alaska Department of Fish and Game banned the use of fish traps in Alaska and began attempting to limit access (with varied success) to many salmon fisheries. The second boundary of interest is 1974, the first year that fisheries were governed by the Limited Entry Act of 1973, and also one of the first years that

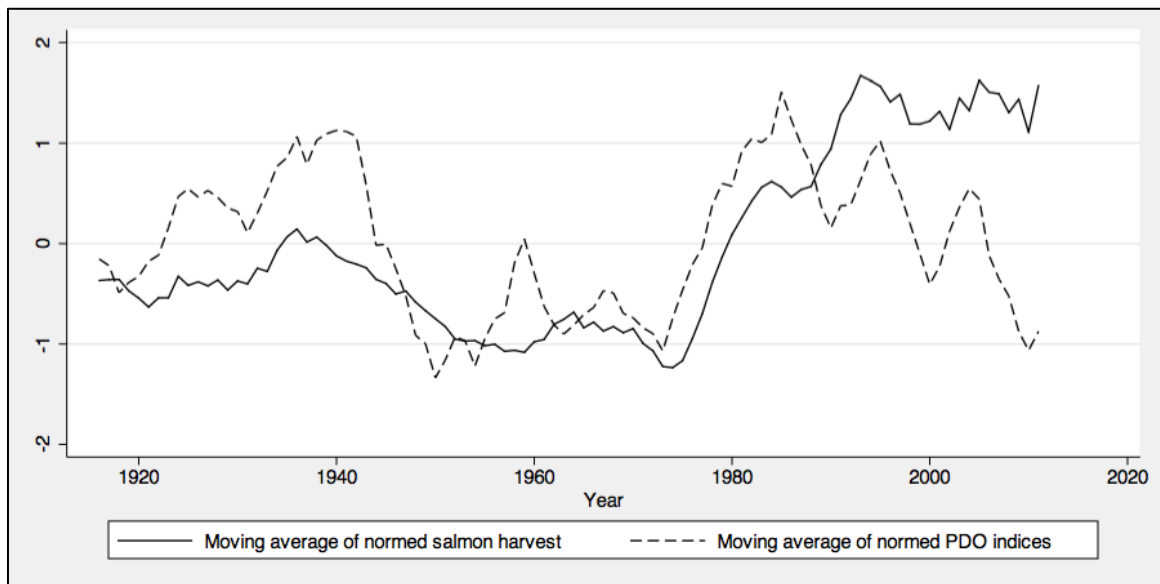


Figure 3: Normed salmon harvests and PDO indices, 1914-2013

significant volumes of salmon were released from developing hatcheries. Both 1959 and 1974 serve as useful reference dates for major shifts in policy and management of Alaska fisheries.

Through statistical modeling of the appropriate time series, this thesis proposes to investigate the short-run and long-run effects of environmental factors (represented by the PDO index), policy changes in 1959, and policy changes in 1974 had on salmon harvests. This analysis will look at each of the five Alaska salmon species independently before combining their long-run results to make broader claims about the statewide salmon industry as a whole.

Chapter 2 Empirical Framework

The investigation of policy effectiveness in connection with both biological and environmental factors lends itself directly to time series analysis. There are many different methodologies and frameworks to consider. After a careful analysis it becomes clear that the most appropriate process for handling this time series is with autoregressive distributed lag with bounds testing approach to cointegration.

2.1 Mixed Order of Integration

Time series data can often be characterized by two different types of self-integration. Stationary time series can be described as following a stochastic (random) pattern centered about a consistent mean. This type of time series is often called a “random walk” and is mathematically characterized as having a constant expected value. More complex time series are sometimes described as having a unit root. Unit root time series are a specific family of nonstationary time series in which 1 is a solution to the characteristic equation. This becomes a problem when conducting the usual Ordinary Least Squares (OLS) regression, as time-series that has a unit root can lead to misleading coefficients and spurious regression. With regard to the order of integration, stationary time series are said to be $I(0)$, while unit root processes are described as $I(1)$. Dealing with $I(1)$ variables can be challenging enough without the tools of OLS, but mixing them with $I(0)$ variables in analysis can be even worse.

The first challenge to consider with regards to combining biological and environmental data is the order of integration of each time series. The work already done

with Pacific decadal oscillation (PDO) indicate that the sea surface temperature fluctuates around a constant mean (Mantua et al., 1997; Mantua & Hare, 2013). This indicates that the PDO index may be characterized by a random walk. Since the PDO index values are normalized to the standard normal curve ($\mu_x = 0$, $\sigma_x = 1$), it is reasonable to guess that the time series PDO_t will be stationary. Since the PDO index values follow a standard normal distribution, it might be assumed to be stationary; however, a unit root test can still be used to validate this assumption.

A glance at Figure 1 and Figure 3 suggest that salmon harvest volumes have increased over the past century. While this may not be true for each species individually, the general trend does indicate that the time series process at work could be a random walk with trend. If this is true, the salmon harvest series will be integrated with order 1, that is they will exhibit a unit root and be $I(1)$. Eventually, a DF-GLS test for unit root will demonstrate that indeed the salmon harvest data series are $I(1)$ for all species.

With a mixture of $I(0)$ and $I(1)$ variables a necessity, it is important that a statistical process be found that can handle both types of variables. While one option is to take the first difference of the $I(1)$ variables, the interpretation becomes less intuitive. Instead, the ARDL approach to cointegration (Pesaran, Shin, & Smith, 2001) will be applied.

2.2 Cointegration

When dealing with multivariate time series, a second concern is the issue of cointegration. Two variables are cointegrated if there exists a linear combination of those variables that is stationary ($I(0)$). Another way to think about cointegration, is that two

variables are cointegrated if they share a random walk process; intuitively this suggests that the variables would wander together. Often this can be characterized as two random variables that both increase because of similar relationships to exogenous factors, or decrease together for similar reasons. Cointegration is a problem because if time series that show a unit root process are used in regression, the cointegration with the trending data may lead to spurious regression.

The literature shows repeatedly that ocean conditions as expressed by the PDO and similar indices are connected with salmon populations throughout the Pacific (Beamish & Bouillon, 1993; Francis et al., 1998; Hare, Mantua, & Francis, 1999; Mantua et al., 1997; Miller & Schneider, 2000; Mote et al., 2003; Mueter, Peterman, & Pyper, 2002; Noakes et al., 1998). This large body of work connecting the two variables lends strong credibility to the idea that there is likely a long-run relationship between the PDO index and salmon population and harvest in Alaska fisheries. Because of this, it will be necessary to test for cointegration between the two variables. Unfortunately, because the two variables that will need to be tested for a long-run relationship are not integrated of the same order, the options for what type of test to use become very limited. Fortunately, the ARDL approach is often used in conjunction with an F-based bounds testing approach to testing for cointegration.

2.3 The ARDL(p, q) Model

The challenge of producing unbiased linear estimators for a time-series model is significant. Vector autoregressive processes are available for analysis with a single

lagged variable, but when the dependent and independent lagged variables are integrated with different order estimates can become inconsistent and biased. To confront this issue, the autoregressive distributed lag (ARDL) modeling approach was developed and refined by Pesaran and Shin (1997). The ARDL methodology estimates the linear coefficients to models that include current and lagged year values of multiple variables. While it is possible to include many variables and their chosen lags, this paper will look to include both salmon harvest data and PDO index. The strength of the ARDL approach is that lags of different lengths are allowable for each variable, and the time series variables themselves are allowed to be any mix of $I(0)$ or $I(1)$ integration. Furthermore, cointegration relationships can be quantified through the ARDL process, and regressive relationships found will not be spurious.

Because of the inherent challenges of dealing with time series data that have different orders of integration and likely long-run cointegration relationships, ARDL methods have been used in the recent decade to investigate a number of economic relationships. Sultan (2010) used the ARDL approach to investigate elasticity of demand for gasoline. Morley (2006) studied long run connections between per capita economic growth and immigration using the ARDL methodology. The ARDL method was even used to investigate cointegration relationships with regard to CO₂ emissions in China (Jalil & Mahmud, 2009). The broadening use of the ARDL model speaks to its robust nature in dealing with both $I(0)$ and $I(1)$ variables in both the short-run and long-run. Of particular interest is also the error correction models that accompany the ARDL structure, and allow for an analysis of the extent to which variables are cointegrated and the

magnitude of the time series correction between them (Banerjee, Dolado, & Mestre 1998).

The benefits of using the ARDL method and bounds testing approach to cointegration make it a good fit for this research. The complexity of the variables involved will be handled by the ARDL framework as well as the bounds testing approach to cointegration. The resulting models will allow for both short-run and long-run interpretations of the coefficients for all included parameters, both endogenous and exogenous. And finally, the error correction aspect of the model will give an insight into the strength and nature of the cointegration relationship beyond the bounds test. The next chapter will describe the data available for the study before moving on to a more detailed description of the $ARDL(p, q)$ modeling process in Chapter 4.

Chapter 3 Data

In order to investigate the short and long run relationships between yearly salmon harvests, oceanic environment, and policy changes, three sets of time series variables are required. In the following chapter, the structure and format of these data sets are described, and their strengths and weaknesses are identified. The time series addressed throughout this paper involves a complete data set from 1914-2013. This provides 100 yearly observations to work with and reliable data for every necessary variable.

3.1 Alaska Salmon Data

Yearly data for salmon harvests are available through various historical publications of the Alaska Department of Fish and Game (ADFG), and in compiled forms from other salmon fishery researchers. Data from 1914-1997 was gathered from the work of Byerly, Brooks, Simonson, Savikko, and Geiger (1999), while data from 1998-2013 was pulled from the Alaska Department of Fish and Game's published commercial salmon harvest data. While a preliminary analysis of the relationship between salmon harvest and PDO index was conducted prior to this thesis using total harvest data, it was important for this work to look at each of the five species of salmon in Alaska separately.

The life cycles of salmon are well studied and documented. In an analysis of how lagged harvest values and lagged ocean conditions impact contemporary salmon harvest, it must be acknowledged that the five types of salmon – Chinook, sockeye, coho, pink, and chum – have different life cycles, expected life expectancy, and different demands on their environment for survival (Ruggerone & Nielsen, 2009; Eggers, 2009; Farley,

Murphy, Moss, Feldmann, & Eisner, 2009). Because of this, this work breaks up the analysis of salmon harvests into five subsets. In order to make this happen, the time series data set includes five distinct variables.

Table 1 shows the summary statistics for each of the five salmon specie harvests for the time period 1914-2013. In connection with those values, Figure 4 shows the harvest numbers for the same time period for each of the five salmon species. What these values and graph demonstrate is that all five salmon species appear to have had similar low harvests between the identified 1959 and 1973 boundaries, as well as similar increases from 1973 onward. In addition, these descriptions show that pink and sockeye salmon have the largest proportions of the overall salmon harvest. As the relationship between salmon harvests and other parameters is investigated, significant factors for those salmon species should carry greater weight in the overall model than coefficients in the Chinook salmon model.

Table 1: Summary statistics for salmon harvests, 1914-2013

Salmon harvest values are listed in thousands of salmon

| Variable | Observations | Mean (\bar{x}) | Std. Dev. (s_x) | Min | Max |
|-----------------|---------------------|------------------------------------|-------------------------------------|------------|------------|
| Chinook | 100 | 633.24 | 149.13 | 281 | 1038 |
| Sockeye | 100 | 25907.69 | 14207.66 | 4490 | 64300 |
| Coho | 100 | 3114.4 | 1600.85 | 1014 | 9560 |
| Pink | 100 | 56805.21 | 38736.32 | 6559 | 219160 |
| Chum | 100 | 9823.28 | 4867.96 | 2722 | 24290 |

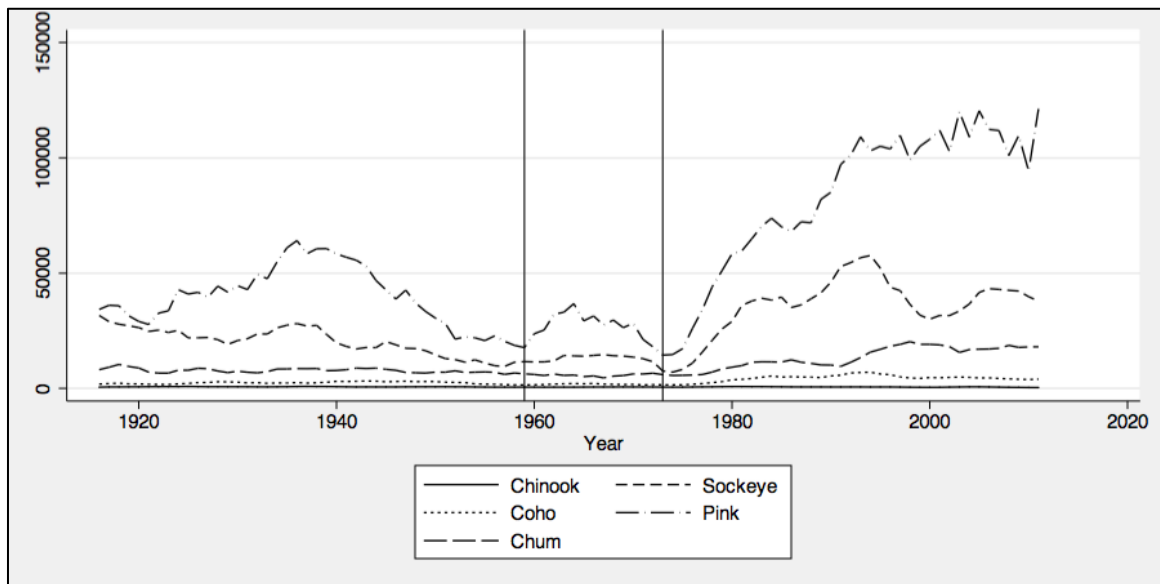


Figure 4: Yearly harvest values (in thousands of fish) for each salmon species

Because the magnitude of harvest levels for the five different salmon species differs so greatly – with pink salmon yields an average of 100 times greater than that of Chinook salmon – the logged values will be used for most of the analysis instead. This helps linearize the data for the purpose of model adequacy, and leads to interesting economic interpretations of the short- and long-run ARDL models. For a more meaningful comparison, the logged yearly harvest values are provided for the time period 1914-2013 in Figure 5. As with the previous plot, vertical lines help delineate the dates of interest: 1959 and 1973.

The salmon harvest data has been compiled from official reports from the ADFG, and can be trusted as a reliable measure of salmon harvests in Alaska salmon fisheries for the given time period. Other researchers have used the same data sources (Eggers, 2009; Knapp, 2013) or subsets of this same data set (Byerly et al., 1999) for their own work, so

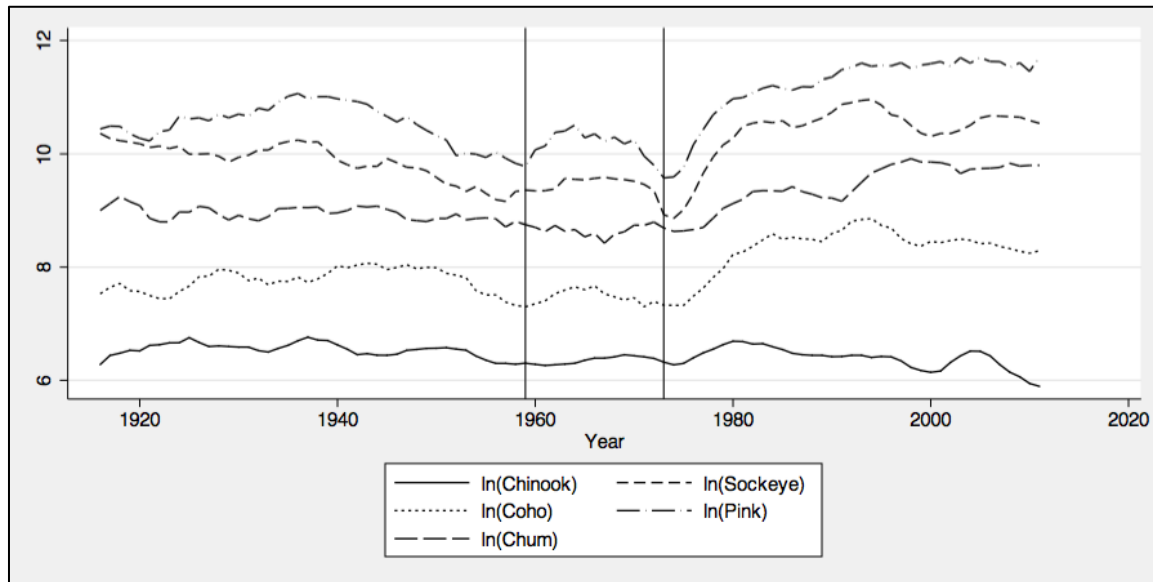


Figure 5: Logged yearly harvest values for each salmon species

there is precedence for using this ADFG data for analysis. It is important to acknowledge, however, that the reliability of measurement procedures has likely increased greatly as time has proceeded. It may be generally assumed that the data is more precise and accurate in recent years than one hundred years ago. It is also important to note that the harvest data is generally being used as a proxy for salmon population.

Throughout this paper the discussion about salmon harvest implies that greater salmon populations lead to higher harvest and vice versa. Certainly other factors – the global demand for salmon, market price, and number of producers – would play a role as well. For the purpose of the paper, however, it is assumed that those factors are connected closely with the time periods investigated. The oversimplification is made that in each of the three ranges of time being studied, that those extraneous factors did not

change significantly. If they did, those changes will be considered a function of the policy climate, and that those policy conditions enabled those changes. Significant changes could emerge as structure breaks in the analysis, and may be identified when looking at the CUSUM and CUSUMSQ plots.

3.2 PDO

The conditions of the Pacific ocean and the salmon's environment is indicated by the PDO index (Mantua & Hare, 2013). The index for Pacific decadal oscillation is a geospatial average of sea surface temperature (SST) across the Pacific ocean. The PDO values are represented as standard normal values with a lifetime mean of 0 and a standard deviation of 1. While the original time series data set was given as monthly averages, these were then combined by a weighted average to give yearly values so as to coincide with the yearly salmon harvest data. Table 2 provides summary statistics of the PDO index for the time period 1914-2013. While the greater monthly PDO data set is norm referenced, it is reassuring to see the yearly averages fit a similar distribution, lending credibility to the idea that sea surface temperature is likely stationary in the given time frame.

Table 2: Summary statistics for PDO index, 1914-2013

| Variable | Observations | Mean (\bar{x}) | Std. Dev. (s_x) | Min | Max |
|----------|--------------|--------------------|---------------------|--------|-------|
| PDO | 100 | -0.0224 | 0.8096 | -1.947 | 1.995 |

The PDO index as compiled by Mantua and Hare (2013) is represented well in the literature as a data source for Pacific climate trends and variability. This data set has been used to draw connections between salmon production in Alaska and the Pacific northwest (Hare et al., 1999), to investigate the possible inverse relationship between sea temperature and salmon success (Mueter et al., 2002), and to propose how climate change may impact fisheries, waterways, and forests in the future (Mote et al., 2003). The PDO index is not the only oceanic climatic index used in empirical work, as others like the Aleutian Low Pressure Index (ALPI) was used by Noakes et al (1998) in their analysis of the connection between salmon abundance and climate variability. Together, studies like these support the inclusion of the PDO index in this model as a proxy for environmental fluctuation.

The PDO index is not perfect, however. As with the salmon time series, the PDO index measurements are likely more reliable in recent decades than at the beginning of the twentieth century. Another challenge that the PDO index presents is the reality that this measure is a weighted average of sea surface temperatures for the entire Pacific Ocean. Alaska salmon from different regions of Alaska and of different species migrate to different regions of the Pacific ocean. Because of this, narrower trends in specific regions of the ocean are not well represented by the index as a whole. Just as with the salmon data, this time series presents one of the most reliable historic measures of Pacific Ocean conditions and will be used throughout the analysis.

3.3 Policy Shifts

The final set of time series that will be necessary to construct the desired ARDL model are a pair of binary variables to represent key time periods in Alaska history. The first will be called *state* and will take on a value of 0 for all yearly observations prior to 1959, when Alaska was a territory, and equal 1 for all years 1959 and later. The mean value of this indicator variable is 0.55, since 55% of the years in the times series come after Alaska had become a state. The inclusion of this variable will help the model look at both short- and long-run impacts of statehood on the harvest of salmon in Alaska fisheries.

The second binary variable will refer to the enactment of the Limited Entry Act and will be called *limentry*. This variable will be 0 for years prior to 1974, and 1 for years 1974 through 2013. The mean of this variable is 0.4, since 40% of the years in the time series follow the passage of the Limited Entry Act. This will reflect the recent time period under which the Alaska Department of Fish and Game has been able to manage Alaska fisheries under a limited entry system, as well as the time frame during which both state and private non-profit hatcheries have been most strongly supported. By including this variable, the constructed ARDL models will be able to describe the short- and long-run impact of these policy shifts on salmon harvests.

By using both of these binary variables in the model, our time series is essentially divided into three regimes. The first runs from 1914-1958, where Alaska was a territory of the United States, and oversight of the salmon fisheries was loosely handled by the federal government. The second runs from 1959-1973, where Alaska was a new state

and their Department of Fish and Game was able to ban the fish trap and attempt to limit other practices in salmon fisheries. Finally, the most recent regime runs from 1974-2013 and describes the system currently in operation in Alaska where the ADFG runs a limited entry system and has a strong record of supporting the efforts of both public and private salmon hatcheries.

Chapter 4 Empirical Procedures

Various time series methods exist for working with the kind of data gathered. As suggested earlier, the process that will be followed here is an autoregressive distributed lag (ARDL) with bounds testing approach. The overall process will be conducted five separate times – once for each salmon species – and the results combined to look at the overall impact of various policy shifts on the harvest of Alaska salmon. For each of the species analyses, the first step will be to conduct tests for stationarity and unit root of the variables of interest. It is important for the ARDL process that all of the variables used are integrated of order 0 or 1. That is, no process is $I(2)$ or greater. The second step is to clarify the structure of the model, including which variables will be used. They are, of course, the variables described in the previous chapter.

The third step is to test the joint significance of the first order lags of the possibly cointegrated factors. In this case, that means testing that each salmon species is cointegrated with the PDO index. To do this, a simple F-test is used and the corresponding F-statistic compared to the 95% confidence bounds offered by Pesaran et al (2001) for the bounds test for cointegration. Satisfied that the salmon harvests have a long-run relationship with PDO, the $ARDL(p, q)$ model will be constructed, with the lags p on salmon harvest, and q on PDO index chosen based on the Schwarz criterion. The stability of the model can be confirmed next using the model diagnostics for serial correlation, functional form, normality, and heteroskedasticity. In addition, the recursive cumulative sum (*CUSUM*) and cumulative sum of squares (*CUSUMSQ*) tests can help guarantee model stability in the presence of possible structure break. Once the results

have been confirmed and are considered reliable, the coefficients will give insight into the short-term impacts of the various explanatory variables, as well as the long-run effects of ocean climate, statehood, and recent policy choices on Alaska salmon harvest.

4.1 Tests for Stationarity and Unit Root

The first step in the ARDL(p, q) modeling process is determining the order of integration for each of the variables. For each of the variables listed, STATA is used to conduct the Dickey-Fuller GLS (DF-GLS) test for unit root. The results for the level test and the test of the first differences (when necessary) are given in Table 3. The results show that the PDO index is stationary ($I(0)$), but that all series of logged salmon harvests demonstrate a unit root.

Table 3: Test Statistics for Dickey-Fuller GLS

| Variable | DF-GLS Level | | DFGLS First Difference | | Conclusion |
|---------------------------|--------------|----------------|------------------------|----------------|------------|
| | Lags | Test Statistic | Lags | Test Statistic | |
| <i>PDO</i> | 1 | -4.494** | | | I(0) |
| <i>ln(Chinook)</i> | 1 | -2.918 | 1 | -7.757** | I(1) |
| <i>ln(Sockeye)</i> | 5 | -1.790 | 4 | -4.051** | I(1) |
| <i>ln(Coho)</i> | 1 | -2.282 | 1 | -7.551** | I(1) |
| <i>ln(Pink)</i> | 1 | -2.158 | 1 | -5.022** | I(1) |
| <i>ln(Chum)</i> | 4 | -1.902 | 3 | -4.149** | I(1) |

Note: Significance is indicated at the 5% (*) and 1% (**) significance levels.

One of the most heralded characteristics of the $ARDL(p, q)$ modeling technique and bounds testing approach is the ability for these processes to handle a mixture of $I(0)$ and $I(1)$ variables (Pesaran et al., 2001; Sultan, 2010; Morley, 2006). This will work well for the data as described, since each $ARDL(p, q)$ model will incorporate lagged values of one of the logged species time series – $I(1)$ in every case – as well as present and lagged values of the PDO index, $I(0)$. The important characteristic of these variables is that none of them have an order of integration larger than 1. This is required by the ARDL bounds testing approach (Pesaran et al., 2001), and is a criteria that is met by the compiled data.

4.2 Model Specification

The general $ARDL(p, q)$ model for each salmon species can be described as shown in equation (1). In this equation, logged harvest value is regressed upon the lag of harvest values for the same species, current and lagged valued of the PDO index, and the indicator variables $state_t$ and $limentry_t$. In addition, the year has been included as a trend term to help reflect the growing capacity of the fishing industry and the demand for its product over the past century.

$$\begin{aligned} \ln(species_t) = & \sum_{i=1}^p \beta_1 \Delta \ln(species_{t-i}) + \sum_{j=0}^q \beta_2 \Delta PDO_{t-j} + \beta_3 state_t + \\ & + \beta_4 limentry_t + \beta_5 year + \lambda_1 \ln(species_{t-1}) + \lambda_2 PDO_{t-1} + \varepsilon_t \end{aligned} \quad (1)$$

Once estimated, the coefficients β_k will give short-run relationships between the dependent and independent variables. In a similar manner, the coefficients λ_k will provide a description of the long-run relationship defined as the cointegration relationship. In the end, these coefficients will be attained and assessed for each of the five salmon species; the lag lengths p and q of the ARDL(p, q) model will be chosen using the Akaike criterion assuming that cointegration relationships are found using the up-coming F-test and bounds testing approach.

4.3 Tests for Cointegration

In order to begin justifying the existence of the cointegration relationship between each species of salmon and the PDO index, it is appropriate to use the bounds-testing procedure outlined by Pesaran et al (2001). This hypothesis test looks to test a set of hypothesis about the coefficients λ_1 and λ_2 from equation (1). In this F-test for joint significance, the null hypothesis is that the coefficients together equal zero ($H_0: \lambda_1 = \lambda_2 = 0$), against the alternative that they are not zero ($H_a: \lambda_1 \neq \lambda_2 \neq 0$). In other words, the null hypothesis is that the two variables $\ln(species_{t-1})$ and PDO_{t-1} are not cointegrated, and the alternative is that they are cointegrated. In order to further justify the use of ARDL modeling to look at long-run relationships, the F-test ideally rejects the null hypothesis indicating that a statistically significant long-run relationship exists.

Looking through Table 4 shows that most of the salmon harvests are cointegrated with the PDO index values. This means that there will likely be a significant long-run relationship between the $\ln(species_t)$ and the PDO_t . However, the F-statistic for the

Table 4: Results of bounds test for cointegration.

Bounds provided by Pesaran et al (2001)

| Variable tested with PDO_t | Suggested lags (p, q) | F Test Statistic | 95% Lower Bound | 95% Upper Bound | Conclusion |
|------------------------------|-------------------------|------------------|-----------------|-----------------|------------------|
| $\ln(\text{Chinook})$ | (1,3) | 18.23 | 6.606 | 7.423 | cointegrated |
| $\ln(\text{Sockeye})$ | (6,4) | 19.83 | 4.934 | 5.764 | cointegrated |
| $\ln(\text{Coho})$ | (2,1) | 7.10* | 6.606 | 7.423 | Indeterminate |
| $\ln(\text{Pink})$ | (2,1) | 4.36 | 6.606 | 7.423 | Not cointegrated |
| $\ln(\text{Chum})$ | (5,3) | 7.90 | 6.606 | 7.423 | cointegrated |

Note: Significance of the F-statistic at the 10% significance level indicated with (*)

time series of $\ln(\text{Coho}_t)$ is not larger than the 95% upper bound. This means that we cannot claim with 95% confidence that the relationship between coho salmon harvest will be cointegrated with the PDO index. The value is larger than the corresponding bounds for 90% confidence (5.649,6.335) and so there is still a possibility of cointegration, and the ARDL(2,1) model will be generated to investigate further.

Finally, the F-statistic for pink salmon is below both the 95% and 90% critical bounds. This indicates that there is likely no long-run cointegration relationship between $\ln(\text{pink}_t)$ and the PDO_t . The ARDL(2,1) model can still be constructed so as to be compared with the other four models, but the coefficients on the various PDO_{t-k} variables will all likely be insignificant. This does not make the ARDL method incorrect, but will yield coefficients similar to the usual OLS results.

Brandt and Williams (2006) describe the challenges of using F-tests for cointegration with lagged models. When working with vector autoregression or autoregressive

distributed lag models, the length of the lag can greatly impact the value of the F-statistic and – consequently – the power of the test itself. If the lags are too short to allow the error terms to become stationary white noise, then the F-statistics are unreliable. Because of this, the ARDL with error correction technique can be used to further investigate the existence of cointegration relationships. In instances like the possible cointegration of PDO with $\ln(\text{Chinook})$ or $\ln(\text{Sockeye})$, the conclusions of the bounds test will likely be confirmed by the statistical significance of the error-correcting term in the corresponding ARDL model. For $\ln(\text{Pink})$ and $\ln(\text{Coho})$ where the bounds test suggests that maybe a cointegration relationship does not exist, looking to this secondary measure can shed new light on the situation.

4.4 Model Coefficients

With the groundwork set for the construction of an $\text{ARDL}(p, q)$ model for each of the five Alaska salmon species, the next step is to construct the models using Microfit 4.1. As described, the lag order of the models is decided based upon the Akaike criteria, and the resulting short-run coefficients are provided in Table 5. This table is organized to show model coefficients in columns, where the coefficients relative to the model for Chinook salmon harvests are given in the second column of the table. The reader will note that some spaces are left blank. Blank spaces correspond to variables that were not included in that species' respective model.

Table 5: Estimated short-run coefficients of ARDL(p, q) models for each species

| Variable | <i>ln</i> (Chinook) | <i>ln</i> (Sockeye) | <i>ln</i> (Coho) | <i>ln</i> (Pink) | <i>ln</i> (Chum) |
|-------------------------------------|----------------------|----------------------|----------------------|----------------------|---------------------|
| ARDL(p, q) | ARDL(1,3) | ARDL(6,4) | ARDL(2,1) | ARDL(2,1) | ARDL(5,3) |
| $\Delta \ln(\text{species}_{t-1})$ | 0.442 (4.645)** | 0.624 (6.144)** | 0.319 (3.213)** | 0.229 (2.409)* | 0.349 (3.292)** |
| $\Delta \ln(\text{species}_{t-2})$ | | -0.023 (-0.199) | 0.286 (2.827)** | 0.427 (4.378)** | 0.225 (2.191)* |
| $\Delta \ln(\text{species}_{t-3})$ | | -0.094 (-0.873) | | | -0.049 (-0.476) |
| $\Delta \ln(\text{species}_{t-4})$ | | 0.200 (1.933) | | | 0.4501 (4.332)** |
| $\Delta \ln(\text{species}_{t-5})$ | | 0.309 (3.019)** | | | -0.173 (-1.754) |
| $\Delta \ln(\text{species}_{t-6})$ | | -0.309 (-3.420)** | | | |
| ΔPDO_t | 0.046 (1.787) | 0.129 (2.522)* | 0.003 (0.062) | 0.006 (0.092) | 0.037 (0.939) |
| ΔPDO_{t-1} | 0.075 (2.557)* | -0.161 (-2.726)** | 0.071 (1.621) | -0.082 (1.206) | -0.009 (-0.216) |
| ΔPDO_{t-2} | -0.004 (-0.131) | 0.196 (3.307)** | | | -0.15 (-0.357) |
| ΔPDO_{t-3} | -0.063 (-2.481)* | 0.0628 (1.001) | | | 0.063 (1.613) |
| ΔPDO_{t-4} | | -0.131 (-2.364)* | | | |
| <i>state</i> _{<i>t</i>} | 0.042 (0.629) | -0.0688 (-0.629) | -0.148 (-1.130) | -0.199 (-1.011) | 0.021 (0.242) |
| <i>limentry</i> _{<i>t</i>} | 0.057 (0.757) | 0.285 (2.307)* | 0.275 (2.221)* | 0.426 (2.247)* | 0.134 (1.265) |
| <i>year</i> | -0.004 (-2.348)** | | 0.002 (0.571) | 0.001 (0.291) | |
| <i>constant</i> | 3.749 (5.909)** | 2.828 (3.182)** | 3.027 (4.034)** | 3.568 (3.529)** | 1.739 (2.103)* |
| <i>ec</i> _{<i>t-1</i>} | -0.558 (-5.861)** | -0.292 (-3.231)** | -0.395 (-3.889)** | -0.343 (-3.395)** | -0.198 (-2.139)* |

Note: Coefficient significance is indicated at the 5% (*) and 1% (**) levels.

T-statistics are in parentheses.

In addition to the short-run coefficients and error correction terms that will be discussed in greater detail in the following chapter, the ARDL modeling technique allows us to compute long-run coefficients for the exogenous variables in the model. Table 6 provides the long-run coefficient estimates for PDO_t , $state_t$, and $limentry_t$ as well as the constant – or intercept - term. It is somewhat reassuring that the long-run intercept coefficients properly indicate the rank ordering of quantities of salmon harvested. Figure 5 showed the moving averages of logged salmon harvest data for each of the five species. There it can be easily shown that the largest percent of the overall salmon harvest is comprised of pink salmon, and similarly, the model for $\ln(pink)$ has the highest estimated constant term. In fact, the ranking of models by constant equates to the ranking of harvest share for each species.

Table 6: Estimated long-run coefficients of ARDL(p, q) models for each species

| Variable | $\ln(\text{Chinook})$ ARDL(1,3) | $\ln(\text{Sockeye})$ ARDL(6,4) | $\ln(\text{Coho})$ ARDL(2,1) | $\ln(\text{Pink})$ ARDL(2,1) | $\ln(\text{Chum})$ ARDL(5,3) |
|-----------------|------------------------------------|------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| PDO_t | 0.097 (1.681) | 0.330 (1.494) | 0.187 (1.701) | 0.258 (1.308) | 0.378 (1.316) |
| $state_t$ | 0.075 (0.625) | -0.236 (-0.640) | -0.374 (-1.284) | -0.582 (-1.136) | 0.104 (0.232) |
| $limentry_t$ | 0.103 (0.756) | 0.976 (2.658)** | 0.697 (2.12)* | 1.242 (1.962) | 0.677 (1.669) |
| constant | 0.721 (75.78)* | 9.699 (52.338)** | 7.661 (36.632)** | 10.400 (28.018)** | 8.78 (39.054)** |

Note: Coefficient significance is indicated at the 5% (*) and 1% (**) levels.

T-statistics are in parentheses.

4.5 Model stability

The final step in the overall ARDL process is to double-check model stability for each of the models. This can be done in two ways, first by checking the diagnostic tests and then by reviewing the CUSUM and CUSUMSQ tests. Table 7 shows the results of the four main diagnostic tests for each of the five models.

The four diagnostic tests help ensure that the overall model has no significant problems with serial correlation, functional form, nonnormality, or heteroskedasticity. It is possible that issues with any of those characteristics of the time series could lend to doubt about the structure of the model. The null hypothesis for the test for serial correlation is that there is no serial correlation in the residuals. As all of the given p-values are large, there are no serial correlation problems in our models. The small p-values for both $\ln(\text{Chinook})$ and $\ln(\text{Sockeye})$ for the functional form test indicate that

Table 7: Diagnostic test results from ARDL(p, q) models

| Variable | $\ln(\text{Chinook})$ | $\ln(\text{Sockeye})$ | $\ln(\text{Coho})$ | $\ln(\text{Pink})$ | $\ln(\text{Chum})$ |
|---------------------|---|---|--------------------------------------|--------------------------------------|--------------------------------------|
| | <i>ARDL(1,3)</i> | <i>ARDL(6,4)</i> | <i>ARDL(2,1)</i> | <i>ARDL(2,1)</i> | <i>ARDL(5,3)</i> |
| Serial | 0.001 | 0.036 | 0.033 | 0.372 | 2.088 |
| correlation | [0.979] | [0.85] | [0.857] | [0.542] | [0.148] |
| Functional | 8.651 | 5.312 | 0.581 | 0.802 | 1.702 |
| Form | [0.003] | [0.021] | [0.446] | [0.370] | [0.192] |
| Normality | 1.625 | 1.138 | 1.534 | 5.033 | 1.344 |
| | [0.444] | [0.566] | [0.464] | [0.081] | [0.511] |
| Hetero- | 1.012 | 1.881 | 0.360 | 8.264 | 2.812 |
| skedasticity | [0.314] | [0.170] | [0.548] | [0.004] | [0.094] |

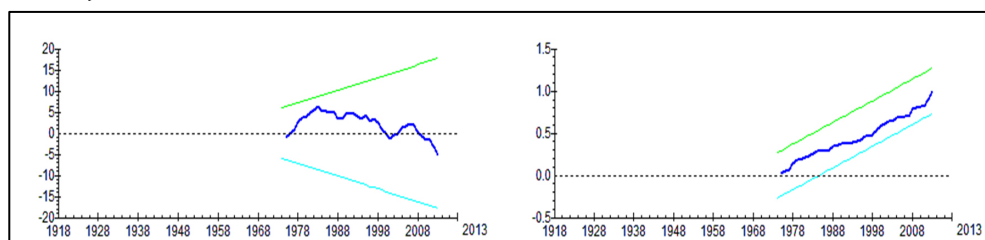
Note: Brackets indicate p-values of the corresponding hypothesis test.

future research could investigate the structure of those models. It is possible that a transformation other than the natural logarithm may provide a better model. The large p-values in the tests for normality indicate there are no problems with non-normality throughout the models. Finally, the test for heteroskedasticity shows that only the model for $\ln(Pink)$ may suffer from heteroskedasticity issues. To learn more, it is worth checking out the CUSUM and CUSUMSQ bounds tests.

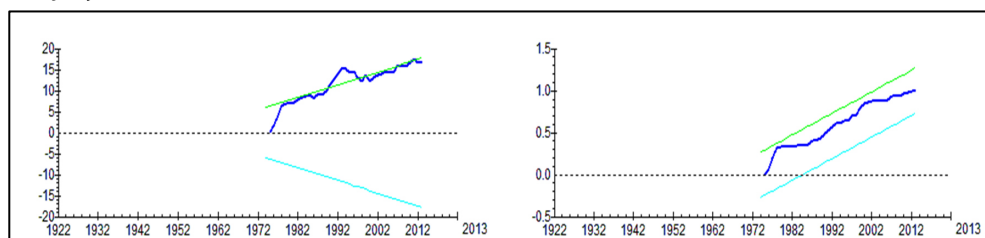
For each model, a pair of graphs helps depict the stability of the model over specific time periods during which a structure break may occur. A structure break is a point in the time series when a shock to the system has occurred, significantly altering the natural average around which the stochastic data are distributed. Because the changes following the 1973 Limited Entry Act and the associated support of hatcheries seemingly increased harvests so much, it is worth checking for how well-specified each model is.

The plots shown in Figure 6 display the cumulative sum of recursive residuals (CUSUM) on the left, and the cumulative sum of the squares of recursive residuals (CUSUMSQ) on the right. A well-defined and stable model would be demonstrated by the central plots staying between the 5% critical bounds for its entirety. The model for $\ln(Chinook)$ shows this well, and this – along with the corresponding p-values for the $\ln(Chinook)$ model in Table 6 reassure the researcher that this model does a good job of describing the variability in $\ln(Chinook)$ values for the time period 1914-2013. The graphs for the $\ln(Coho)$ and $\ln(Pink)$ models are also adequate, especially when combined with the diagnostic test results from Table 6.

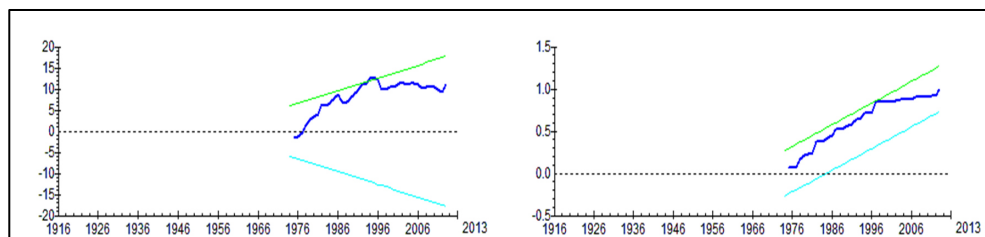
$\ln(\text{Chinook})$



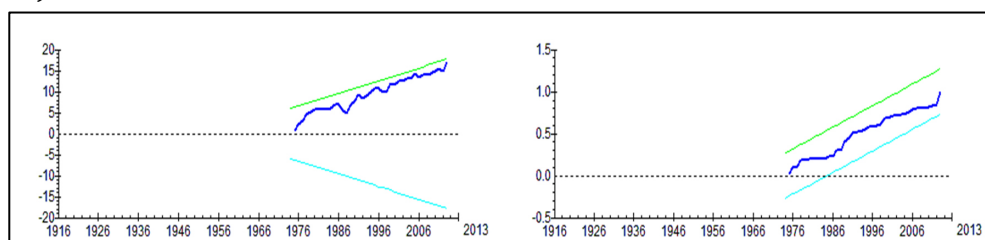
$\ln(\text{Sockeye})$



$\ln(\text{Coho})$



$\ln(\text{Pink})$



$\ln(\text{Chum})$

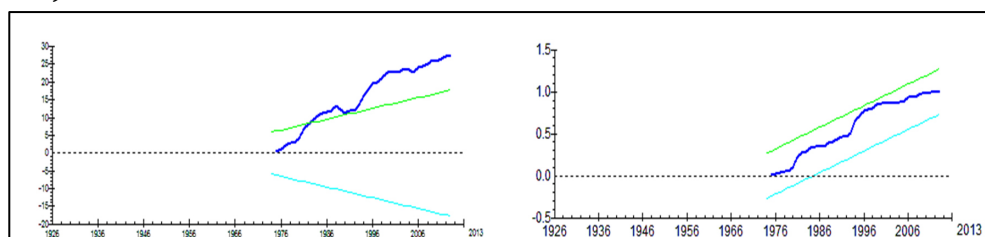


Figure 6: CUSUM and CUSUMSQ tests for each model

Note: In each, the straight lines represent critical bounds at the 5% level

The only graphs that lead to any serious concern are the CUSUM plots for $\ln(\text{Sockeye})$ and for $\ln(\text{Chum})$. The graph of $\ln(\text{Sockeye})$ CUSUM reaches above the upper critical bound for the years 1992 through 2000. While it returns to the proper range and stays there for the rest of the time period, this fluctuation and the low p-value for the functional form diagnostic test suggests that maybe a modification to the function could yield a stronger model. Similarly, the CUSUM plot for $\ln(\text{Chum})$ shows a significant break. The diagnostic tests all suggest that the model is sound, but the shape of the CUSUM plot indicates that the residuals grow too large too quickly for a model that is well-specified. Initial attempts to correct this through various lag lengths or the exclusion of trend and intercept terms had strong negative impacts on the rest of the model. It appears as though, given the current data set and model parameters, that this structure break might not be able to be accounted for simply.

Chapter 5 Empirical Results

This next chapter will discuss each of the models in more depth. First, the fitted values for each model will be graphed in comparison to the observed harvest numbers to provide a visual cue for the strength and abilities of each model. The discussion about model stability will be continued for each salmon species, and the values and significance of both short-run and long-run coefficients will be investigated. Unique characteristics of each model will also be outlined, and the long-run effects of specific exogenous variables will be combined to answer the original policy questions.

5.1.1 Models: Chinook Salmon

Possibly one of the strongest models overall, the ARDL(1,3) model seems to be well-defined. The \bar{R}^2 of the model as a whole is 0.55816, and the diagnostic tests, CUSUM, and CUSUMSQ all suggest that the model is reasonable. Figure 7 shows the fitted values from the model and the observed logged values for Chinook salmon harvest. A visual analysis suggests that the model does a good job of describing the overall trends in harvest volume, but does not fully capture some of the extreme values.

When the short-run coefficients from Table 5 are considered, it can be noted that the first lagged value of $\ln(\text{Chinook})$ is positive and significant. While the life span of Chinook salmon is much longer than one year, it is reasonable to conclude that rising harvests would continue from year to year. This significant coefficient may be an indicator of fishing trends rather than biological connections. Also significant are the

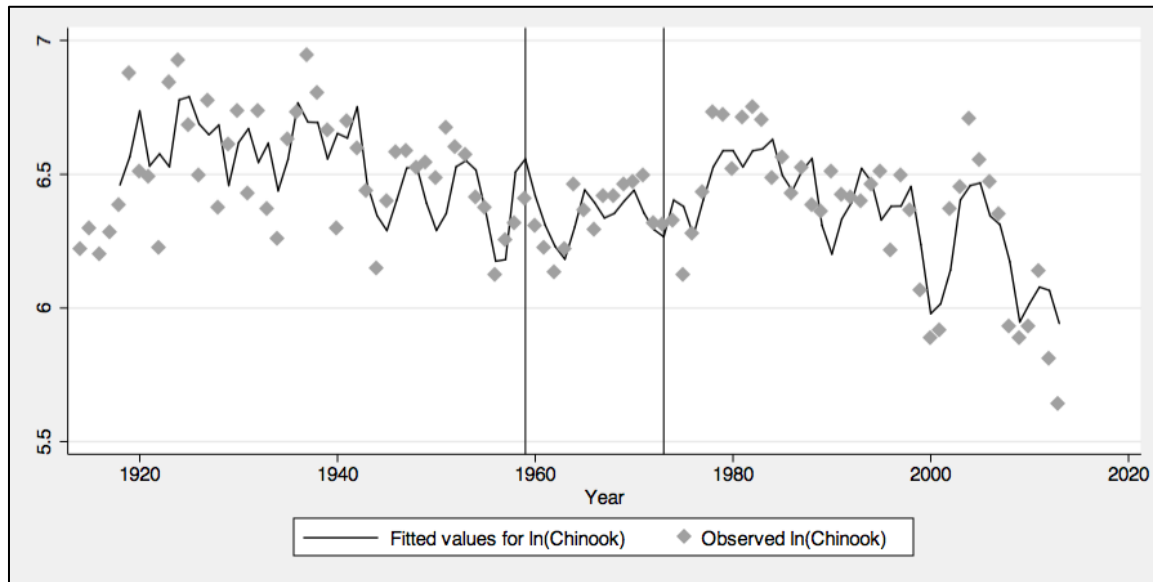


Figure 7: Fitted and observed values for $\ln(\text{Chinook})$ from 1914-2013

short-run coefficients on the first and third lag of the PDO index, which suggests that ocean conditions may play a role in the survivorship of Chinook salmon cohorts at different times in their lives in the ocean. Because of the log-level relationship between the dependent variable and the lagged PDO values, we can interpret these to suggest that an increase of 1% in the PDO will likely increase the harvest volume of Chinook salmon in the following year by 7.5%. Similarly, an increase this year in the PDO of 1% will likely cause a decrease in future Chinook harvests of 6.3%. These seemingly contradictory relationships have a net positive value, but may also suggest that oceanic conditions that favor salmon of one age may harm salmon of a different age. Finally, both coefficients for the binary variables $state_t$ and $limentry_t$ are insignificant. This implies that the changes in policy and governance structure in 1959 and again in 1974 had no statistically significant impact on the volume of Chinook salmon harvest.

The error correction term for the $\ln(\text{Chinook})$ model is statistically significant at the 1% level, and has a value of -0.558. This means that in the long run, the variability in values of $\ln(\text{Chinook})$ do not deviate from the fluctuations of the PDO index for long. The error correction term of -0.558 explains that if the previous year's $\ln(\text{Chinook})$ value differs from the equilibrium value, the fleet usually adjusts by approximately 55.8% of the deviation in the following time period. This series of adjustments suggests first that the Chinook salmon harvest volumes lag behind changes in the PDO index, and that the adjustment is rather quick, taking about two fishing seasons to correct the overall error.

Finally, the long-run coefficients in this model are worth mentioning since none of them are significant on their own. This suggests that the stock of Chinook salmon is likely very stable on its own, and that policy changes have not impacted it much. All of the coefficients are positive, and while not significant, they may indicate that higher PDO values are better for Chinook salmon, and that the changes in 1959 and 1973 did not harm Chinook salmon populations or harvests.

5.1.2 Models: Sockeye Salmon

The ARDL(6,4) model for $\ln(\text{Sockeye})$ is shown in Figure 8. The \bar{R}^2 of the model as a whole is 0.76510, and as with the Chinook model the diagnostic tests, CUSUM, and CUSUMSQ all support the idea that the model for $\ln(\text{Sockeye})$ gives a reasonable estimation. A visual analysis of the fitted values as they travel through the observed $\ln(\text{Sockeye})$ data shows that the model is best at approximating the values in the most

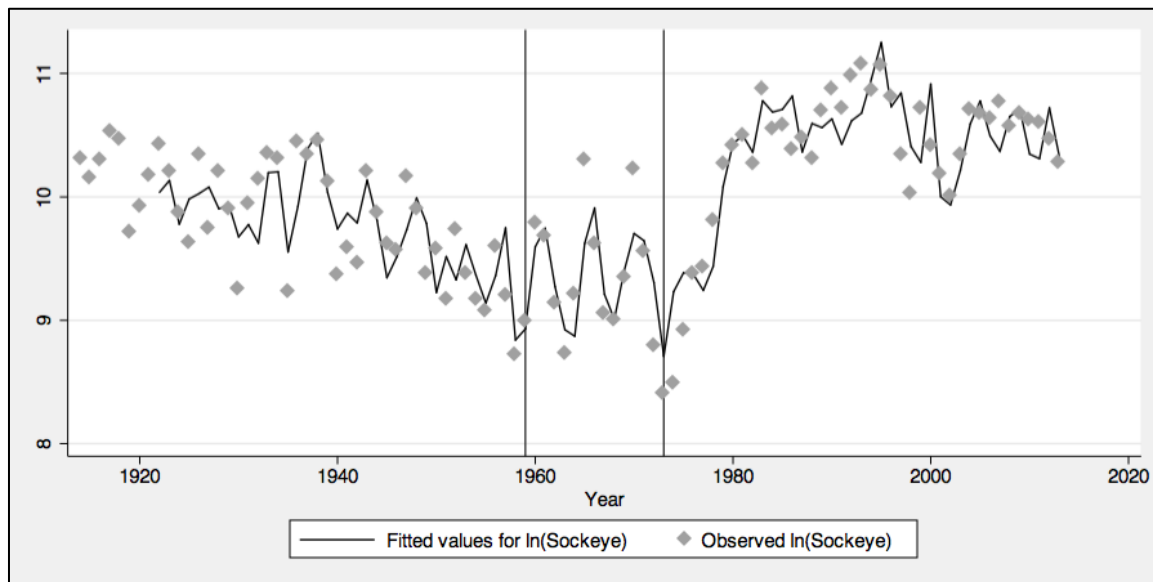


Figure 8: Fitted and observed values for $\ln(\text{Sockeye})$ from 1914-2013

recent regime from 1974 to today. Overall, the predicted values seem to capture most of the variability in the observed data, with the exception of a few extreme values in the early part of the time series, and in the range from 1959 to 1974.

The short-run coefficients from the model are given in Table 5, and show the kind of relationships suggested by the literature. Past $\ln(\text{Sockeye})$ harvest impacts current harvest, where the previous year's significant coefficient indicates that higher harvest last year will indicate higher harvest in the current year as well. This is likely reflecting the influence of market demand on changing harvest volumes. The 6-year lag shows a significant negative impact, where higher harvest at the 6-year lag lead to significantly less harvest in the current year. With the lifespan of sockeye salmon extending up to 7 years, this relationship may be connected to the lifecycle of the salmon, suggesting that overharvesting may impact the size of future generations of sockeye salmon.

Also significant in the short run are the PDO index values. The significant lagged values are all about the same magnitude and alternate in sign as they move backward in time. This is confusing, as it is generally assumed that – depending on species – higher or lower PDO values would be better for the salmon environment. These numbers indicate that fluctuations may impact the sockeye salmon populations in different ways at different ages, or in different parts of the ocean as salmon travel throughout their lives. This is not unexplored, as the work of Mueter et al (2002), Hare et al (1999), and Noakes et al (1998) all investigated the various relationships – both positive and negative – between ocean climate, PDO, and salmon populations.

Finally, the binary variables $state_t$ and $limentry_t$ can be considered. The coefficient on $state_t$ is insignificant, and negative. The negative sign may indicate that with statehood, the ban on fish traps decreased sockeye salmon harvest in the short run. While insignificant, the sign of the coefficient does support the logic expected, and the same pattern is seen in the coho and pink species as well. The coefficient of $limentry_t$ is positive and significant, telling us that the changes that took place in 1974 with the Limited Entry Act and the accompanying support of hatcheries had the desired positive impact on sockeye salmon harvest.

The error correction term for this model is significant, supporting the initial assumption that $\ln(Sockeye)$ and PDO were cointegrated (Table 4). The coefficient of -0.292 indicates that as $\ln(Sockeye)$ lags behind changes in PDO, each year the sockeye salmon harvests adjust toward equilibrium by about 29.2%. This change is not as quick as it was for Chinook salmon, but the larger volume of harvest for sockeye salmon – a

ratio of sockeye to Chinook catch of nearly 44:1 – may suggest that it takes longer to adjust the overall harvest volume.

The long-run coefficient for the PDO is positive but not significant at the 5% significance level. The positive sign suggests what much of the literature has proposed, that higher PDO values are better for the sockeye salmon harvests and population in the long-run. Also insignificant is the coefficient for the binary variable $state_t$. While insignificant in the long run, the negative sign of the value -0.236 does suggest the policy impact of banning the fish trap as mentioned earlier. Finally, the coefficient of 0.976 is statistically significant for the variable $limentry_t$. This value promotes the idea that policy changes following 1974 had a significant positive effect on the harvests of sockeye salmon in Alaska fisheries.

5.1.3 Models: Coho Salmon

One of the shortest models, the ARDL(2,1) model for $\ln(Coho)$ reflects many of the same indicators as the previous two, as well as the impact of the shorter life cycles of coho salmon in comparison to Chinook and sockeye. The model has an overall \bar{R}^2 equal to 0.67832, and with some of the most convincing diagnostic test results and CUSUM and CUSUMSQ plots, the model will be considered adequate for our purposes. The graph of the fitted values for $\ln(Coho)$ are paired with the observed harvest volumes in Figure 9.

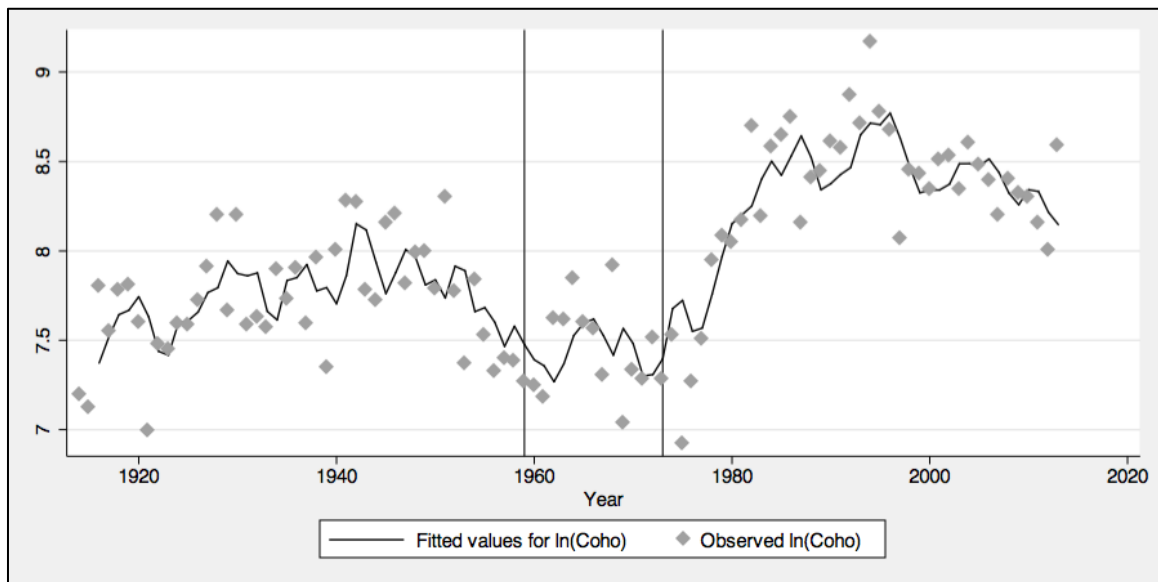


Figure 9: Fitted and observed values for $\ln(Coho)$ from 1914-2013

Coho salmon have a life span of one to two years, and as a result, the included lags for this model – two for the $\ln(Coho)$ values, and one for the PDO series – do not extend very far into the past. The Akaike criterion was used to select the lag order, and this indicates that the biological circumstances may only affect the coho harvest values for a few periods. Still, the two lagged values for coho harvest were both positive and significant, indicating that as harvest volumes begin to move, they continue to move in that direction for a few seasons.

The PDO index was insignificant at the 5% level for both the present time and the first lag. With such short lifespans, it is reasonable to assume that fluctuations in ocean conditions may not play as large a role in the success of the coho salmon cohort from year to year. Still, the coefficients were positive, indicating that higher PDO values may have helped support higher harvest numbers.

The binary variable for $state_t$ is negative, but insignificant as it was with the sockeye salmon. While the impact may not be significant, the sign on the coefficient suggests that the ban on fish traps and other changes in 1959 may have lessened harvests in the short run. $Limentry_t$, on the other hand, has a positive and significant coefficient. This supports the same ideas as with the previous species, that the shifts in 1974 had a strong positive overall effect on coho salmon harvests.

Also of interest is the error correction term of -0.395, which is significant at the 1% level. The initial F-test for cointegration (Table 4) was inconclusive, but with a statistically significant ec_t term, we see that a long-run cointegration relationship is likely. The term itself suggests like the previous species that as PDO moves, adjustments in coho salmon harvest lag behind, and correct toward the equilibrium value by about 39.5% per year. Other long-run relationships for coho harvests are similar to those for the sockeye salmon. The long-run coefficient for PDO is positive but insignificant, and the long-run coefficient for $state_t$ is negative and insignificant. Of special interest though is the significance of the coefficient for the $limentry_t$ variable. This coefficient is 0.697, and its positive sign suggests as before that changes in 1974 had a positive and significant impact on the harvest of coho salmon.

5.1.4 Models: Pink Salmon

The other salmon with a relatively short life cycle of only one to two years is the pink salmon. The ARDL(2,1) model for $\ln(Pink)$ harvest values has an adjusted \bar{R}^2 of 0.64290, reasonable CUSUM and CUSUMSQ plots, and diagnostic tests that – for the

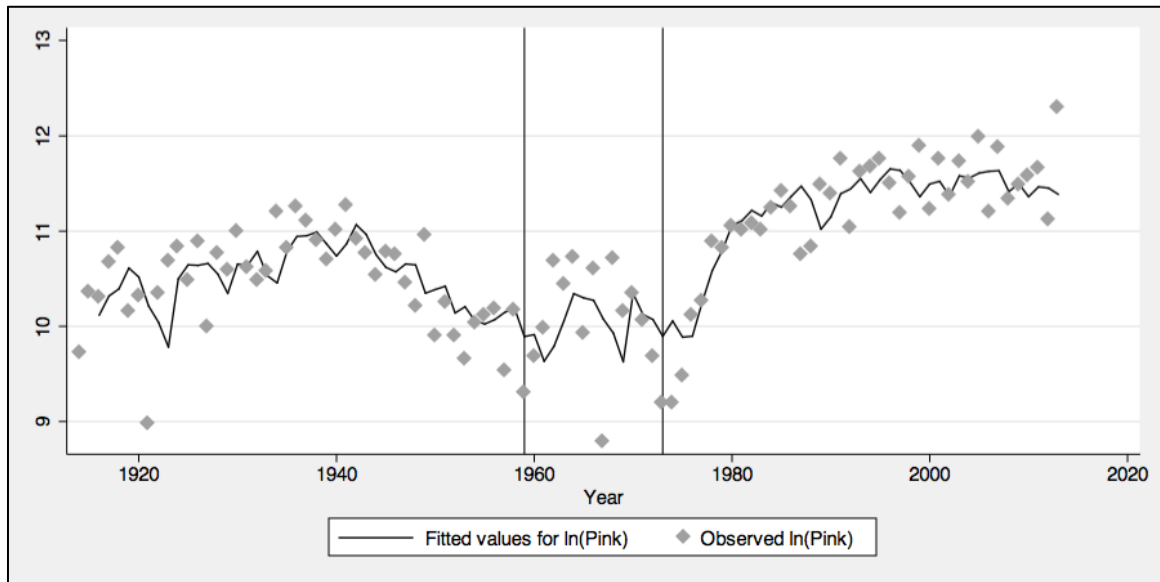


Figure 10: Fitted and observed values for $\ln(Pink)$ from 1914-2013

most part – support the use of this model for this research. The only questionable point is that the diagnostic test for heteroskedasticity rejected the null hypothesis of homoskedasticity. This may be an indicator that the model has issues, but the reasonable \bar{R}^2 will encourage a discussion anyway. The fitted values are graphed along with the observed $\ln(Pink)$ harvest data in Figure 10.

The short-run coefficients for the $\ln(Pink)$ model are extremely similar to those of the $\ln(Coho)$ model. The two included lags for $\ln(Pink)$ are both positive and both significant, suggesting that harvest trends continue in the short-run. This is likely a reflection of the ability of the fleet to adjust its production levels in the short-run. Both of the included lags of PDO are insignificant, and both are small in magnitude, suggesting that the short life span of pink salmon means that ocean conditions play a small role in the success of the salmon.

The short-run coefficient for $state_t$ is insignificant, but negative in sign as with coho salmon, and the coefficient for $limentry_t$ is positive and significant. Both of these relationships continue to support the idea that changes in 1959 had little impact on salmon harvests, but may have slightly decreased harvest volumes in the short run if anything. Also, the changes associated with 1974 likely did have the desired impact of bolstering pink salmon harvests.

The error correcting term from the error correcting model (ECM) is -0.343 and is significant at the 1% level. As with each of the salmon species, this encourages the idea that harvests of pink salmon adjust toward changes in the PDO. Each year, disequilibrium between $\ln(Pink)$ and PDO is corrected by about 34.3% by subsequent changes in harvests of pink salmon. This also indicates a cointegration relationship, despite the low F-statistic (Table 4) from the bounds test for cointegration. This discrepancy suggests that future work looking at assessing the existence of cointegration relationships would be warranted.

The long-run coefficients show that for pink salmon the effect of PDO may be positive, but the calculated coefficient is insignificant. Similarly, the long-run effects of statehood may be negative, but the associated coefficient is also insignificant. Even the suggested relationship to the policy changes following 1974 – while positive in sign – are only significant at the 10% level. Together, all of this may be a reflection of the short life span of pink salmon, or possibly bias resulting from potential heteroskedasticity problems. Each of the coefficients has the expected sign, but their insignificance at the 5% level indicates that further work might be necessary.

5.1.5 Models: Chum salmon

The ARDL(5,3) model for $\ln(\text{Chum})$ harvest has an \bar{R}^2 equal to 0.73956, and good results to the diagnostic tests. Unfortunately, the CUSUM plot shows that a likely structure break in the early 1980s that threatens the overall stability and validity of the model in the most recent decades. The fitted values for the model are graphed along with the plotted observed harvest values are shown in Figure 11.

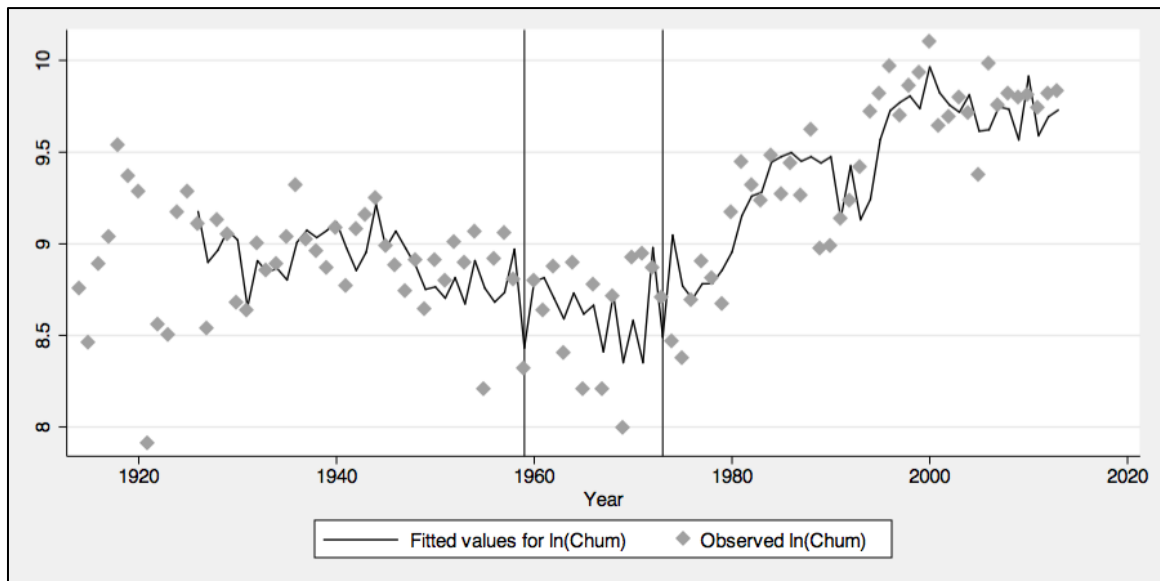


Figure 11: Fitted and observed values for $\ln(\text{Chum})$ from 1914-2013

The short-run coefficients for the lagged $\ln(\text{Chum})$ harvest values are nearly all significant for at least the 10% significance level, while the signs of the coefficients of the strongly significant are all positive. This suggests that higher harvests lead to continuing high harvests in subsequent years. This could be a reflection of market trends,

or it could be a result of the problems with model stability during the years of rapid increase following 1974.

None of the lags for PDO are significant, and their small magnitudes indicate that for the chum salmon the PDO does not impact their yearly harvests. Even the coefficients for $state_t$ and $limentry_t$ are insignificant, and while the $limentry_t$ variable does have the expected positive sign, the results are likely unreliable due to the instability of the model for the time period following 1974.

The error correction term is negative and significant just as it was for each of the preceding harvest models. This is somewhat reassuring as it suggests the same relationship exists for Chum salmon: that when harvest values lag behind the PDO index, the cointegration relationship (suggested by the F-test described in Table 4) shows that chum harvest correct toward equilibrium by about 19.8% each year.

The long-run coefficients of the model are all positive, and all insignificant at the 5% level. The PDO coefficient is positive as with the rest of the salmon species, suggesting once again that if a relationship does exist, it is likely a positive one. Similarly, the coefficient on $state_t$ is positive, indicating as with the Chinook harvests that changes in 1959 may have actually increased chum salmon harvests. Finally, the coefficient for $limentry_t$ is 0.677 and is significant at the 10% level (p-value of 0.099), suggesting that perhaps the changes in 1974 could have had the strongest positive influence on chum salmon harvest. Unfortunately, each of these relationships is tentative at best until a more stable $\ln(Chum)$ model can be developed.

5.2 Policy Assessment and Long Run Relationships

The center of this thesis is the overall long-run relationships between Alaska salmon harvests and policy changes in 1959 and 1974. The changes in 1959 began with Alaska statehood and developed for fisheries as control and oversight for the Alaska salmon industry transferred to state control, the fish trap was banned, and efforts to limit entry into some of those fisheries began (*Starbound*, 2009). In 1974 a recent change to the Alaska Constitution allowed for the Limited Entry Act and the more stringent control over the number of fishing operators in each fishery. At the same time, the ADFG began to build their own state-run salmon hatcheries, as well to support and in some cases subsidize the efforts of private nonprofit salmon hatcheries. Together, these efforts are often cited as the decisions that have led to high salmon harvests in the recent twenty years (McGee, 2003; Homan, 2006).

5.2.1 Alaska Statehood

It is worth recalling the form of the original ARDL(p,q) models that have been discussed so far this chapter. Equation (1), first presented in section 4.2 is reproduced below:

$$\begin{aligned} \ln(species_t) = & \sum_{i=1}^p \beta_1 \Delta \ln(species_{t-i}) + \sum_{j=0}^q \beta_2 \Delta PDO_{t-j} + \beta_3 state_t + \\ & + \beta_4 limentry_t + \beta_5 year + \lambda_1 \ln(species_{t-1}) + \lambda_2 PDO_{t-1} + \varepsilon_t \end{aligned} \quad (1)$$

To address the original research topic about how the ARDL modeling approach can inform the discussion about the long-run effects of policy shifts, the coefficients β_3 and β_4 . These coefficients can give an indication of the long-run impacts of salmon harvests after taking into account the cointegration relationship between harvests and environmental factors. The individual long-run effects have already been discussed in the previous sections, but reconsidering the long-run coefficients with their respective standard errors can give a bigger picture.

Table 8: Estimated long-run coefficients of $state_t$ for each species

| $state_t$ | $\ln(\text{Chinook})$ | $\ln(\text{Sockeye})$ | $\ln(\text{Coho})$ | $\ln(\text{Pink})$ | $\ln(\text{Chum})$ |
|-----------------------|-----------------------|-----------------------|--------------------|--------------------|--------------------|
| | ARDL(1,3) | ARDL(6,4) | ARDL(2,1) | ARDL(2,1) | ARDL(5,3) |
| Coefficient | 0.075 | -0.236 | -0.374 | -0.582 | 0.104 |
| Standard Error | 0.119 | 0.363 | 0.291 | 0.513 | 0.449 |
| T-statistic | (0.625) | (-0.640) | (-1.284) | (-1.136) | (0.232) |

Note: Coefficient significance is indicated at the 5% (*) and 1% (**) levels.

While the individual significance of $state_t$ is interesting for each species, the linear combination of these coefficients gives a better picture. A linear combination of random variables can be constructed such that:

$$\beta_{3_{total}} = \sum_{i=1}^k \beta_{3_i} \quad (2)$$

$$SE_{total}^2 = \sum_{i=1}^k SE_i^2 \quad (3)$$

That is, the expected value of a sum of expected values can be computed simply as the sum. The same is true for coefficients from a model. Similarly, the square of the standard error of a linear combination of random variables can be found as the sum of the squares of the standard errors of each variable independently. Together, these ideas let us sum the long-run coefficients for $state_t$ and calculate a new standard error for this combined coefficient. Doing so gives us interpretable values for how the changes of 1959 impacted salmon harvests overall.

The combined calculation yields a coefficient for the $state_t$ variable of -1.013 with a standard error of 0.834 and an associated test-statistic of -1.215. Even if we do not include the questionable results from the unstable $\ln(Chum)$ model, the overall long-run coefficient becomes -1.117 with a t-statistic of -1.589. These coefficients are insignificant at even the 10% significance level, indicating that the long-run effects of Alaska statehood on salmon harvests was not large. If anything, the sign of the coefficient suggests a negative impact on salmon harvest, likely because of the move away from the use of the fish trap.

5.2.2 Limited Entry Act & Hatchery Support

Constructing the same combined coefficient and standard errors as described in the previous section, a total coefficient for $limentry_t$ can be found that describes the overall impact of changes in 1974 on the salmon industry in Alaska. To do this, the long-run coefficients (Table 9) and their respective standard errors for each of the five species-specific models must be used.

Table 9: Estimated long-run coefficients of $limentry_t$ for each species

| $limentry_t$ | $\ln(\text{Chinook})$ ARDL(1,3) | $\ln(\text{Sockeye})$ ARDL(6,4) | $\ln(\text{Coho})$ ARDL(2,1) | $\ln(\text{Pink})$ ARDL(2,1) | $\ln(\text{Chum})$ ARDL(5,3) |
|-----------------------|------------------------------------|------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Coefficient | 0.103 | 0.976 | 0.697 | 1.242 | 0.677 |
| Standard Error | 0.136 | 0.367 | 0.328 | 0.633 | 0.406 |
| T-statistic | (0.756) | (2.658)** | (2.12)* | (1.962) | (1.669) |

Note: Coefficient significance is indicated at the 5% (*) and 1% (**) levels.

By combining the coefficient and standard error values, we find that the overall salmon harvest industry has a coefficient on $limentry_t$ of 3.695 with a standard error of 0.909 and a t-test statistic of 4.064. Even if the questionable $\ln(\text{Chum})$ values are removed, the coefficient is still 3.01711 with a test statistic of 3.709. In either case, the coefficient is positive and significant at the 1% level.

This indicates that the changes in 1974 created very positive, significant change in the Alaska salmon industry as a whole. Specifically, the coefficient of 3.695 offers that the Limited Entry Act and corresponding hatchery support increased average yearly salmon harvests statewide by $e^{3.695} = 40.246$ million salmon. This increase of more than 40 million salmon harvested per year is tremendous when compared to the five year average harvest from 1970-1974 of 96 million salmon, and is a large percent of the most recent five year average from 2009-2013 of 181 million salmon.

5.2.3 PDO

Much of the literature discusses the interconnectedness between salmon populations and ocean climate (Beamish & Bouillon, 1993; Francis et al., 1998). As proxies, salmon harvests and PDO index have been investigated in this paper to see if the information provided by the PDO can help clarify policy-related issues. The same kind of cumulative coefficient can be constructed using the long-run coefficients and standard errors for PDO included in Table 10.

Table 10: Estimated long-run coefficients of PDO_t for each species

| PDO_t | $\ln(\text{Chinook})$ | $\ln(\text{Sockeye})$ | $\ln(\text{Coho})$ | $\ln(\text{Pink})$ | $\ln(\text{Chum})$ |
|-----------------------|-----------------------|-----------------------|--------------------|--------------------|--------------------|
| | $ARDL(1,3)$ | $ARDL(6,4)$ | $ARDL(2,1)$ | $ARDL(2,1)$ | $ARDL(5,3)$ |
| Coefficient | 0.097 | 0.330 | 0.187 | 0.258 | 0.378 |
| Standard Error | 0.058 | 0.221 | 0.110 | 0.197 | 0.287 |
| T-statistic | (1.681) | (1.494) | (1.701) | (1.308) | (1.316) |

Note: Coefficient significance is indicated at the 5% (*) and 1% (**) levels.

By constructing the linear combination (sum) of these coefficients as in the preceding sections, a coefficient for PDO as it affects overall salmon harvests is found. This overall long-run coefficient is 1.251 with a standard error of 0.431 and a t-test statistic of 2.903. Removing the $\ln(\text{Chum})$ values as suggested earlier maintains a coefficient of the same sign (0.873) and an equally significant test statistic (2.7169). This significantly positive coefficient lends credibility to the widespread claim that salmon harvests are directly impacted by the PDO index, and similarly salmon populations impacted by ocean climate.

Chapter 6 Conclusion

As the analysis of the results wraps up, it is appropriate to return to the original research questions and consider how the various analysis answer the questions posed. In this chapter the results from the various models will be discussed in relation to the original policy questions. Following that, a discussion about the weaknesses of this work and directions for future research will be included. Finally, a comment about the role of statistical modeling in relation to economic policy will conclude the work.

6.1 Response to Initial Questions

The original questions posed in this work were whether or not the policy shifts and other associated changes in 1959 and in 1974 had the intended impact of increasing Alaska salmon harvests in the long-run. It has been discussed that the goal of the statehood movement included the support of salmon fisheries (Cooley, 1963), and that one of the goals of the Alaska Department of Fish and Game is to ensure the sustainability of those same fisheries (Homan, 2006). In response to this claim, this thesis has investigated time series data for each of the five Alaska salmon species, the Pacific decadal oscillation (PDO) index, and binary variables to represent major time periods in Alaska history.

The resulting models for each salmon species can be combined to predict aggregate salmon harvests for the time period 1914-2013. The resulting plot compared with observed total salmon harvests can be seen in Figure 12. It can be noted that the model does the best job of predicting harvests prior to the 1990s.

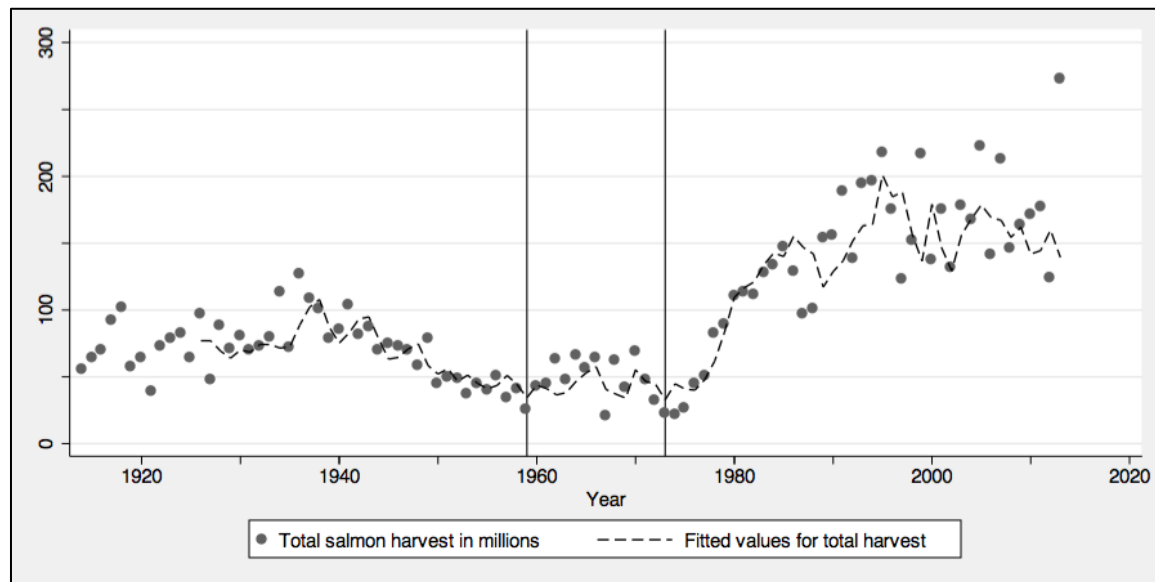


Figure 12: Fitted and observed values for aggregate harvests from 1914-2013

First, this work supports the biological claim that the PDO index and the oceanic conditions that accompany it are connected to the success of salmon populations and, by association, salmon harvest (Beamish & Bouillon, 1993; Francis et al., 1998). By incorporating the long-run cointegration relationship between PDO and salmon harvest, long-run coefficients by species and for the salmon market as a whole were derived for both changes in 1959 and 1974. The coefficients for the changes associated with statehood were overwhelmingly insignificant (none of the six calculated coefficients were significant at the 5% significance level), though most were negative. If a relationship exists, it is likely a negative one; this would not come as a surprise since the first and most successful changes that occurred in 1959 with regards to the salmon industry was the banning of the fish trap, which would necessarily make fishing methods more challenging and less effective on average.

With regards to changes that occurred in 1974, all of the computed coefficients were positive, and most were reasonably significant. This shows that the changes in 1974 – from the implementation of the Limited Entry Act to the support of salmon hatcheries statewide – had a positive and significant impact on the salmon harvest volumes. Of greatest interest is the coefficient for how those changes impacted the overall salmon market, and that expected impact was an increase in the average salmon harvest of more than 40 million fish each year.

6.2 Challenges and Future Direction

A few of the points in this work are left unsatisfying. The possible heteroskedasticity problem identified in the diagnostic test following the ARDL(2,1) modeling of $\ln(Pink)$ harvests is something that could be investigated further. It is possible that heteroskedasticity issues led to inaccurate coefficients, but with the signs of each as expected it is not of great concern at this moment. Also frustrating is the low p-value for the test of functional form for the $\ln(Sockeye)$ model. Sockeye salmon have the longest lifecycle of the five species studied, so it was not a surprise that it also had the longest lags; but the results of that diagnostic test suggest that a different functional form – perhaps other than the use of a logarithm – may produce a better result. Still, with an $\bar{R}^2 = 0.76510$, the accuracy of this model seems adequate for the purpose of this work.

The greatest concern with the model as it stands is the stability of the $\ln(Chum)$ model. The CUSUM plot showed a likely structure break in the early 1980s, suggesting that a different model may be needed to explain the variability in chum

salmon harvests with greater reliability. Even still, with the $\ln(Chum)$ coefficients removed from the linear combinations to create overall salmon coefficients, the sign and significance of each coefficient did not change by much. While the weakness of the $\ln(Chum)$ model does not seem to hurt the overall results of this thesis, it is certainly a place for future study.

Some final directions for future study with regards to the changes in salmon harvest include quantifying the impact that hatcheries had on yearly salmon yields. A series of ADFG reports from the early 1970s through 2013 are available that could provide the number of salmon hatcheries for each species as well as the egg takes and juvenile releases for each year. Incorporating this data may help better explain changes in trends – even structure breaks – for the mid 80s and early 90s as the hatchery program grew. In addition, incorporating economic factors such as exvessel price, aggregate demand, or the cost of labor could help explain any of the variability or long term trends resulting from outside economic forces on the salmon industry.

6.3 Concluding Remarks

The fluctuations in salmon harvests over the past century are clearly connected to ocean conditions. An argument that federal mismanagement alone was responsible for declining salmon harvests in the late 1940s and 1950s would be incorrect, as – it seems – would an argument that Alaska statehood alone led to the rebound in salmon harvest volumes. What can be said is that the conditions that made the significant increases following 1974 would not likely have been possible if Alaska had not been given the

opportunity to manage its own resources through the Alaska Department of Fish and Game. What this thesis really shows is the challenge inherent in trying to model complex bioeconomic issues such as fisheries harvests. Single events such as statehood or the passing of the Limited Entry Act do not occur in a vacuum, and rather accompany other micro and macro changes. Perfect examples are that in 1959 the fish trap was banned, impacting the microeconomic costs and decisions of the salmon industries, while from 1974 onward the open support of salmon hatcheries has impacted the macroeconomic global market for salmon.

Furthermore, the ARDL modeling process does a good job of providing insight into the econometric relationships between a mix of variables. The flexibility of working with both $I(0)$ and $I(1)$ variables without differencing to level them is convenient, and the short-run and long-run interpretations of the results is potentially useful in many contexts. Using species-specific models to make claims about both the individual markets as well as the salmon market as a whole provides a new insight into analyzing complex systems. Future work for developing or assessing policy and managerial decisions should consider ARDL approaches when working with historical data, and time series that may be characterized by long-run cointegration relationships.

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